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Coated Metallic Grains as a Source of Interstellar Absorption Lines

by

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COATED METALLIC GRAINS AS A SOURCE

OF INTERSTELLAR ABSORPTION LINES[1,2]

by

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Abstract.--A. Unsöld has suggested that interstellar absorption bands may be produced by plasma resonance in small metallic particles. This paper describes a theoretical and experimental investigation of this suggestion. It is shown that grains of sodium produce an absorption band at λ3700A. If these grains were to be coated with ordinary ice, the band would shift to the vicinity of the λ4430A band observed in the spectra of highly reddened stars.

Author

Introduction

The most infamous of interstellar absorption lines is the diffuse band at λ4430. This band and a dozen or so lesser companions have remained unidentified for 30 years despite numerous interesting suggestions. (See Appendix for a bibliography on the λ4430 band.)

Figure 1 shows profiles obtained by R. Wilson (1958) of the λ4430 band in two heavily reddened stars. The intensity of this band is strongly correlated with interstellar reddening (Greenstein and Aller, 1950; Duke, 1951) but much less strongly correlated with the intensity of the atomic lines of the interstellar medium, for example the Na D lines. Two recent papers (Stoeckly and Dressler, 1964; Wampler, 1963) have discussed evidence for variations of the slope of the correlation between color excess and λ4430 intensity.

These results suggest that it is plausible to suppose that the λ4430 band is intimately associated with the solid matter causing interstellar reddening.

Recently Professor A. Unsöld (1962)[4] suggested that such bands might be produced by absorption in very small metallic particles. He adduced a sequence of plausibility arguments and pointed out that particles of the alkali metals were likely candidates.

I do not intend to consider plausibilities but rather to explore the properties of Na particles and point out an interesting coincidence.

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[1]Presented at the 116th meeting of the American Astronomical Society, Flagstaff, Arizona, June 1964.

[2]This work was supported in part by grant number NsG 87/60 from the National Aeronautics and Space Administration.

[3]Smithsonian Astrophysical Observatory, Cambridge, Massachusetts

[4]A translation of the Abstract of Prof. Unsöld's paper is given in the Appendix. The reader is invited to examine it at this point.

Colloidal absorption bands

Before proceeding to the theory, let me illustrate the production of colloid bands by small metallic particles.

The colloid absorption spectrum first studied in detail is that responsible for the deep red color of finely divided gold particles. The theoretical work of J. C. Maxwell Garnett (1904) and G. Mie (1908) successfully applied electromagnetic theory to interpret the color variations observed in gold films and goldsols. Figure 2 shows the absorption curves predicted by Mie for gold particles of various diameters suspended in water. Each curve is tagged with the particle diameter in millimicrons (10A). Note that the curves are nearly independent of size for diameters less than several hundred angstroms.

Figure 3 displays absorption spectra measured by Doremus (1964) for goldsols of various dimensions. Agreement with the Maxwell Garnett and Mie theory for small particles is quite good except for particles of diameter less than 50A. For these extremely small particles the effective conductivity of the metal is reduced by electron scattering from the particle walls. Such a reduction of conductivity below the value for bulk gold used in the calculations tends to reduce the prominence of the resonance peak.

In figure 4 is shown the absorption curve for colloidal gold produced in the laboratory at the Smithsonian Astrophysical Observatory. This gold was deposited from vapor onto a silicone oil in an N_2 atmosphere at a pressure of 10^{-2} torr. The curve is very similar to that of Doremus (1964) with a slight shift of wavelength resulting from the change of the matrix.

Figure 5 shows absorption spectra of NaCl taken from the work of W. T. Doyle (1958). The pronounced peak near 2.2 ev (λ5600) is caused by metallic Na particles suspended in the salt. It is my thesis that if these Na particles were embedded in ordinary ice at a temperature sufficiently low to prevent chemical reaction, the colloid band would be shifted to λ4430.

Results of the classical theory

The Mie theory states that if a metallic particle is sufficiently small that the incident wave amplitude is essentially constant across the particle, then we need consider only the induced dipole and can neglect higher terms. (This is the limit employed by Maxwell Garnett, 1904.)

The polarizability of a sphere of radius $\underline{a}$ and complex refractive index $\underline{m}$ embedded in a medium of index $\underline{n_0}$ is

$$p = a^3 \frac{(m/n_0)^2 - 1}{(m/n_0)^2 + 2} \quad . \qquad (1)$$

The effective refractive index of a colloidal suspension of such spheres is given by

$$\bar{m}^2 = 1 + 4\pi\, Np \ , \tag{2}$$

and the corresponding attenuation coefficient for light intensity is

$$K = \frac{36\pi\, NV}{\lambda_0}\; n_0^3\; \frac{nk}{(n^2 - k^2 + 2n_0^2)^2 + 4n^2 k^2} \ . \tag{3}$$

We have written for the complex refractive index of the individual particles

$$m = n - ik \ ,$$

and have defined $\underline{K}$ so that the light intensity varies as $\exp(-K\chi)$ along the light ray.

Note that when $\underline{n}$ is small, the absorption coefficient has a sharp resonance peak at the wavelength for which

$$\frac{k^2}{n_0^2} = 2 \ . \tag{4}$$

The width of the peak will increase with the value of $\underline{n}$, the real part of the refractive index, at the resonant wavelength. It is for this reason that the alkali metals, possessing very small $\underline{n}$ at resonance, can be expected to produce narrow bands. Further, since $\underline{k}$ is a function of wavelength, the condition for resonance, equation (4), states that the resonant wavelength will depend on the refractive index of the medium in which the particle is embedded.

The factor 2 appearing in the resonance condition is a direct consequence of the expression $(m/n_0)^2 + 2$ appearing in the denominator of equation (1). This resonant term in the polarizability will depend rather sensitively on the shape assumed for the grains and on the orientation of the individual grains if they are not spherical. Thus if the metallic grains are not closely spherical, the colloid band which they produce will be appreciably broadened. (A similar conclusion has been reached by van de Hulst, who has extended the analysis to ellipsoidal particles. See Draft Reports, I.A.U. Twelfth General Assembly, p. 507.)

The classical theory for n and k developed by Lorentz and Drude (Unsöld, 1963) treats the electrons and ions within the metal as composing a plasma characterized by an electron density and a well-defined collision frequency. The electrons are considered free while the ions are fixed within the metallic lattice. The collision time, τ, is related to the zero frequency conductivity, σ_0, through

$$\tau = \frac{2\,m_e}{Ne^2}\,\sigma_0 , \tag{5a}$$

where N is the number density of electrons of mass m_e and charge e. The corresponding free path is given by $\Lambda = U_F\tau$ where U_F is the Fermi velocity, the velocity of electrons at the surface of the degenerate sea. For particles smaller than Λ, Doyle (1958) suggests replacing Λ with the particle radius, r, and calculating the mean collision time from $\tau = r/U_F$. For the sake of generality we shall introduce the dimensionless factor S defined with equation (5a) so that the actual collision time is

$$\tau = \frac{1}{S}\,\frac{2m_e}{Ne^2}\,\sigma_0 . \tag{5b}$$

Classical theory provides the following expression for the refractive index of a plasma of free electrons and fixed, but polarizable, ions:

$$m^2 = 1 + 4\pi\,\alpha_0 - \frac{4\pi\,Ne^2}{m_e\,\omega^2}\,\frac{1}{1 - i/\omega\tau} . \tag{6}$$

In this equation α_0 is the ionic polarizability and ω is the circular frequency of the impressed radiation field. Using

$$m^2 = n^2 - k^2 + 2ink,$$

and the following definitions (Ratcliffe, 1959):

$$\omega_p^2 = \frac{4\pi Ne^2}{m_e} ;$$

$$X = \omega_p^2/\omega^2 ;$$

$$Z = 1/\omega\tau ;$$

$$\zeta = 1/(1 + Z^2) ;$$

$$M = 1 + 4\pi \alpha_0 - X\zeta ;$$

$$N = X\sqrt{\zeta(1 - \zeta)} ,$$

we find

$$n^2 - k^2 = M ,$$

$$2nk = N ,$$

and finally

$$n^2 = 1/2 \left\{ \sqrt{M^2 + N^2} + M \right\} ,$$

$$k^2 = 1/2 \left\{ \sqrt{M^2 + N^2} - M \right\} .$$

In a collisionless case the plasma frequency, ω_p , divides the propagating from the nonpropagating frequencies. The corresponding wavelength in vacuum shall be designated λ_c .

These relationships have been thoroughly discussed by Ratcliffe (1959) in the context of ionospheric propagation. We shall turn at once to a specific case, that of sodium, noting that there is a strong qualitative similarity in optical behavior among all the alkali metals.

Application of classical theory to sodium

To this point our argument follows Unsöld. Now we wish to apply this theory to sodium. Table 1 displays the numerical constants for sodium used in these calculations.

The empirical and theoretical behaviors of n and k for bulk sodium are displayed in figure 6. We have adjusted only one parameter in the theory, the quantity S, which is the factor multiplying the classical electron collision-frequency.

The choice S = 3 gives an appreciably better fit to the values of n than the classical value S = 1. On the other hand, the values of k are virtually uninfluenced by the choice of S.

Now we insert these values into the expression for k and adopt n = 1.285. Although the wavelength of the band is sensitive to the refractive index of the matrix, the shape of the band is not. The result is shown in figure 7 which contains hypothetical absorption line profiles computed by assuming the intensity dip to be proportional to the absorption coefficient. The similarity between the profile for S = 3 and the observed profile is indeed remarkable.

Experimental evidence

Seeking further empirical support for this suggested identification of the λ4430 band, Douglas Pitman and I have attempted to detect the colloidal band in the laboratory. Sodium is, of course, rather difficult to handle at room temperature, and we tried several unsuccessful methods. Finally, we resorted to the method used 60 years ago by R. W. Wood.

We evacuated and sealed a glass cell with a small piece of metallic sodium inside. Heating the wall of the cell released vapor, which recondensed on cooler parts of the wall. The recondensed solid produced a thin film, which is pink where it is thinnest.

Figure 8 shows an absorption curve of the pink portion obtained with a Cary Model 14 spectrophotometer at AFCRL in Bedford, Massachusetts.[5] Here we see, superimposed on the continuous absorption of the film, a pronounced band evidently produced by colloidal sodium on this film. The width of the absorption band agrees well with the theoretical profile (figure 7), and the wavelength, λ3600, fits the theory for uncoated particles.

[5] We are grateful to Air Force personnel for their kind assistance in obtaining this absorption curve.

In figure 9 the central wavelength of the colloidal band is plotted against the refractive index of the surrounding medium. The solid line is the theoretical curve obtained by computing detailed band profiles for various values of n_0.

The observed point for collodial sodium in an NaCl matrix, indicated by the triangle, lies several hundred angstroms to the red of the theoretical curve. A similar discrepancy is known to exist for KCl, KBr, and KI (Doyle, 1958). The cause of this discrepancy has not yet been determined, and the principal motivation for our present experiment was to see whether the discrepancy persists for uncoated particles. The new experimental point lies nearly on the theoretical curve for $n_0 = 1$, appropriate to uncoated particles.[6] It therefore appears probable that the source of the discrepancy for NaCl does not lie in the basic theory. Rather, it would appear to lie in a modification of the NaCl structure in the immediate vicinity of the embedded metallic Na particles.

This confirmation of the theory makes it appear quite certain that small Na particles coated with a dielectric of refractive index about 1.285 would produce a band at $\lambda 4430$. The uncertainty of this estimate for the refractive index of the coating is estimated to be about $\pm$ .02 on the basis of uncertainties in the theory and the optical parameters of sodium. Thus any dielectric material with a refractive index in the range $1.27 < n_0 < 1.31$ would be a suitable possibility. Clearly, ordinary ice would be a "suitable" coating from the standpoint of wavelength coincidence. Whether the chemistry of interstellar space allows the production of metallic sodium grains coated with ice is impossible to discuss at present.

The abundance of Na required to explain the observed intensity of the line is, as Unsöld found, about 10^{-8} or 10^{-9} atoms per cc concentrated in particles of diameter less than about 300A. (Larger particles produce a broader band at nearly the same wavelength.) This abundance is not inconsistent with present data.

Conclusion

Small grains of metallic sodium ($d < 300$A) appear capable of producing an absorption band with a width of 100-200A. For uncoated particles the band has been detected in the laboratory at $\lambda 3600$, whereas for particles coated with ice the band will probably lie very near to $\lambda 4430$. This work, by suggesting a specific type of particle, supports Unsöld's suggestion that the diffuse interstellar lines may be colloidal absorption bands.

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[6] This agreement suggests at once the value of looking for an interstellar band in the neighborhood of the Balmer discontinuity.

Table 1.--Parameters for metallic sodium

Kittel (1956), p. 122

Number density, ρ/Am_H	2.54	10^{22}	per cc
D. C. conductivity, σ_0	2.1	10^{17}	c.g.s.
Collision time, $\tau = \frac{2m}{Ne^2}\ \sigma_0$	3.27	10^{-14}	sec
Fermi velocity, U_F	1.07	10^{8}	cm/sec
Free path, $\Lambda = U_F\ \tau$	350A		
Polarizability of Na^+, $4\pi\ \alpha_0$	0.129		
Critical wavelength, λ_c	0.2103		micron

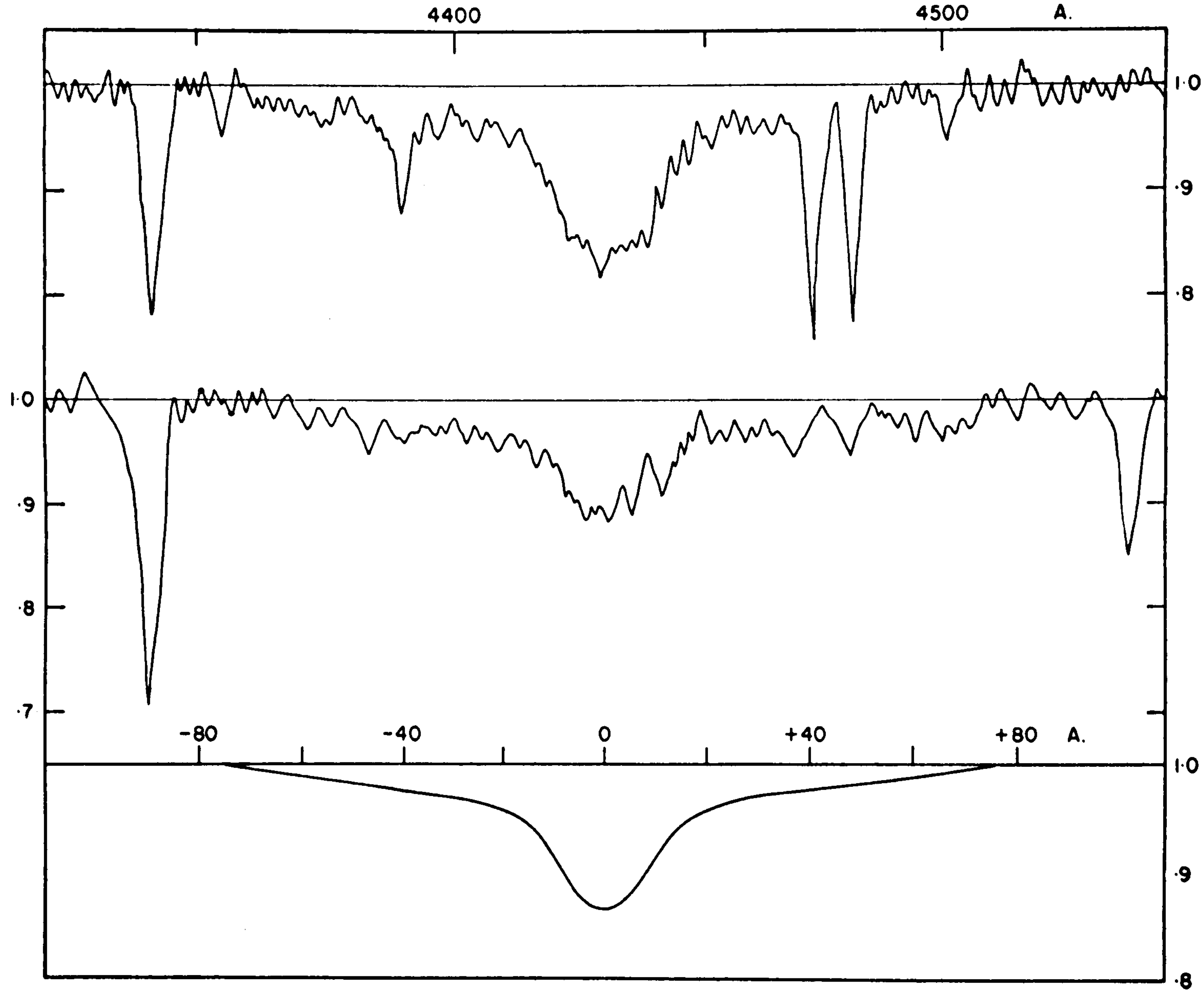

Figure 1.--Intensity tracings of spectra of HD 183143, B7 Ia, and HD 15570, O5f, showing the interstellar band at $\lambda4430$, which extends over a range of some 150A. The smoothed profile of the feature is also given. (Reprinted with permission from R. Wilson, Mon. Not. Roy. Astron. Soc., 1960.)

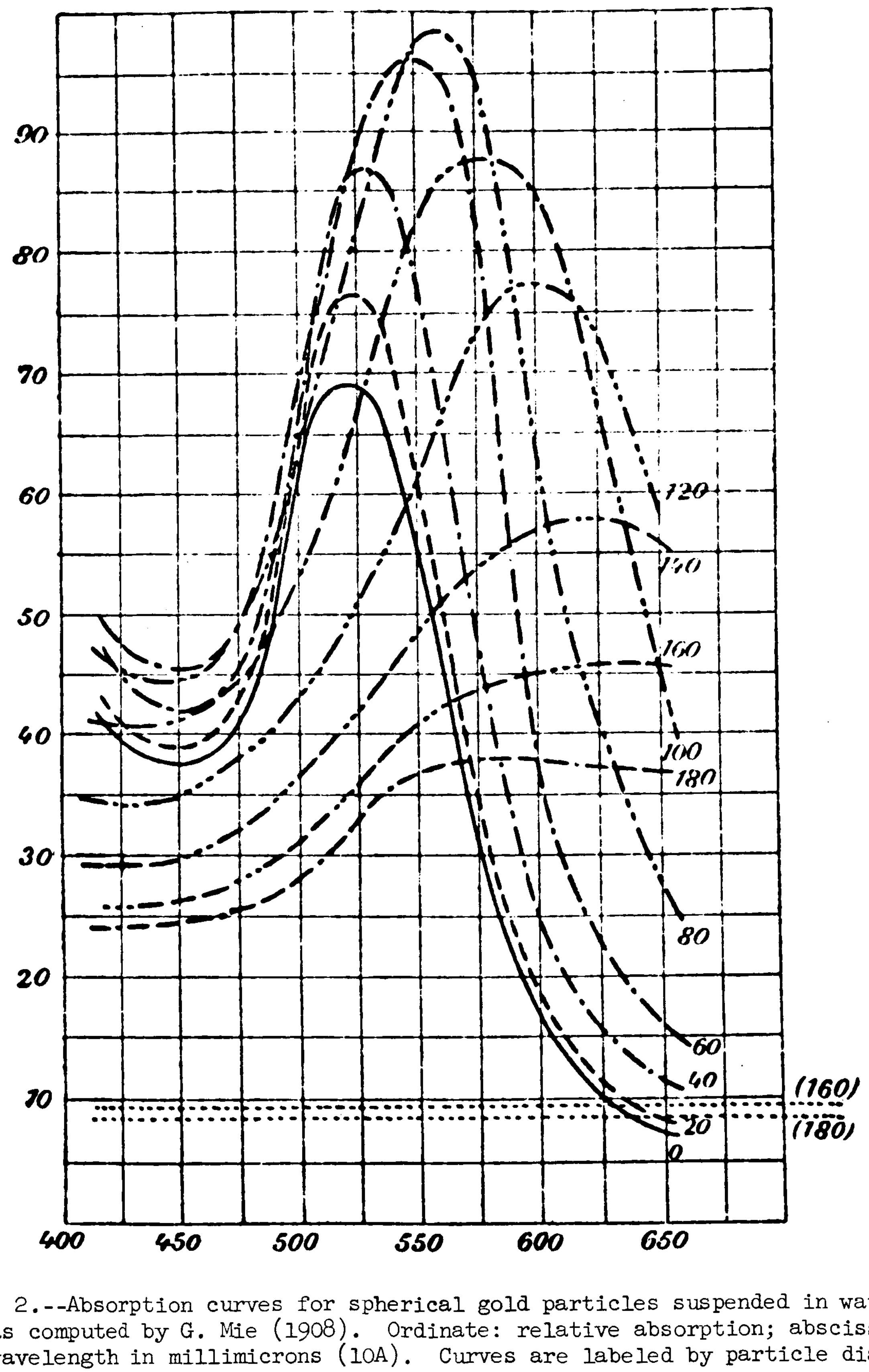

Figure 2.--Absorption curves for spherical gold particles suspended in water as computed by G. Mie (1908). Ordinate: relative absorption; abscissa: wavelength in millimicrons (10A). Curves are labeled by particle diameter in millimicrons.

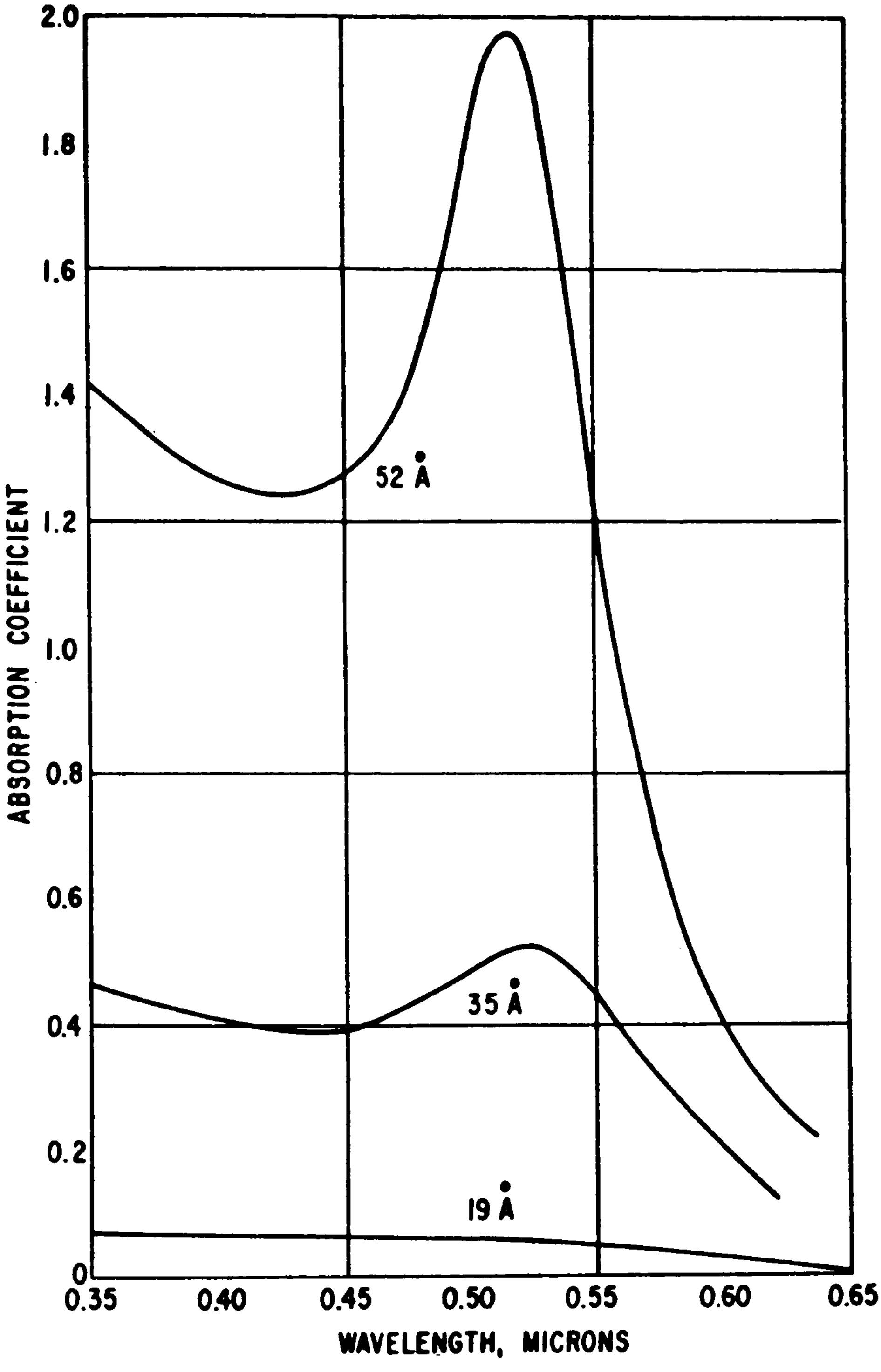

Figure 3.--Absorption spectra of gold particles of different sizes in glass. (Reprinted with permission from R. H. Doremus, Journ. Chem. Phys., 1964.)

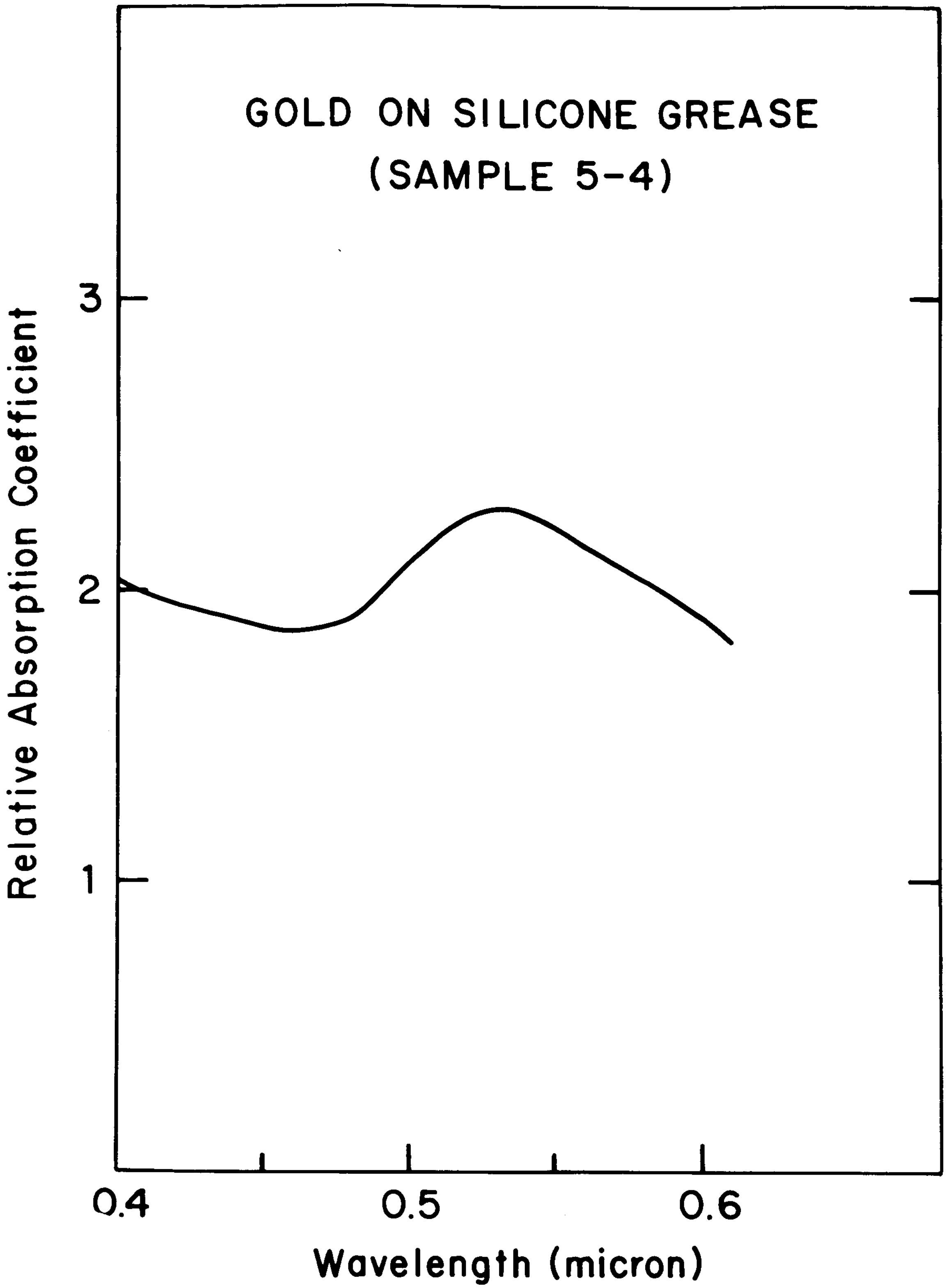

Figure 4.--Absorption spectrum of colloidal gold deposited from vapor onto silicone grease. Sample prepared at Smithsonian Astrophysical Observatory and measured at AFCRL, Bedford, Massachusetts.

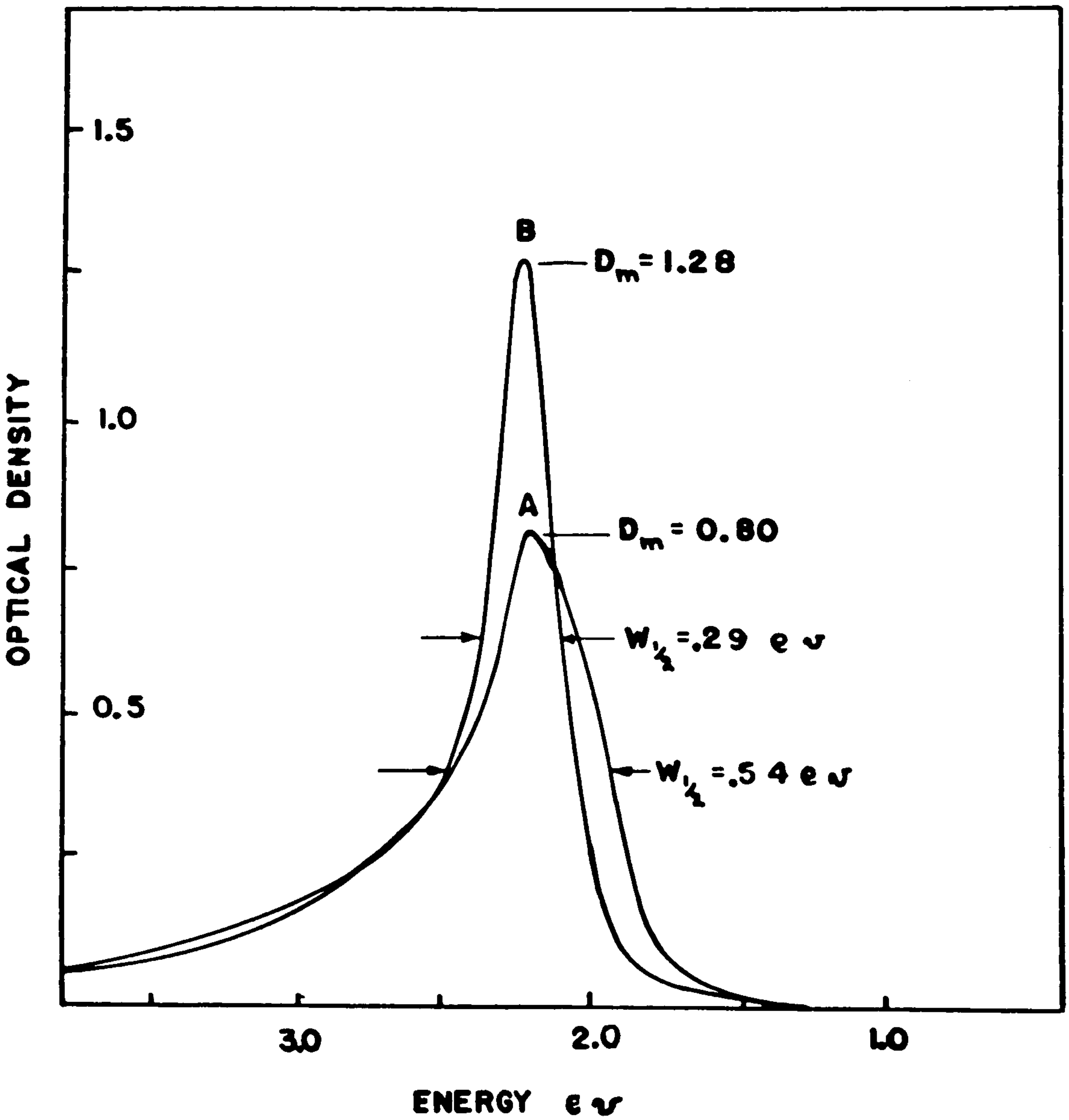

Figure 5.--Colloid band absorption spectra for NaCl. Curves A and B differ in the manner of sample preparation. (Reprinted with permission from W. T. Doyle, Phys. Rev., 1958.)

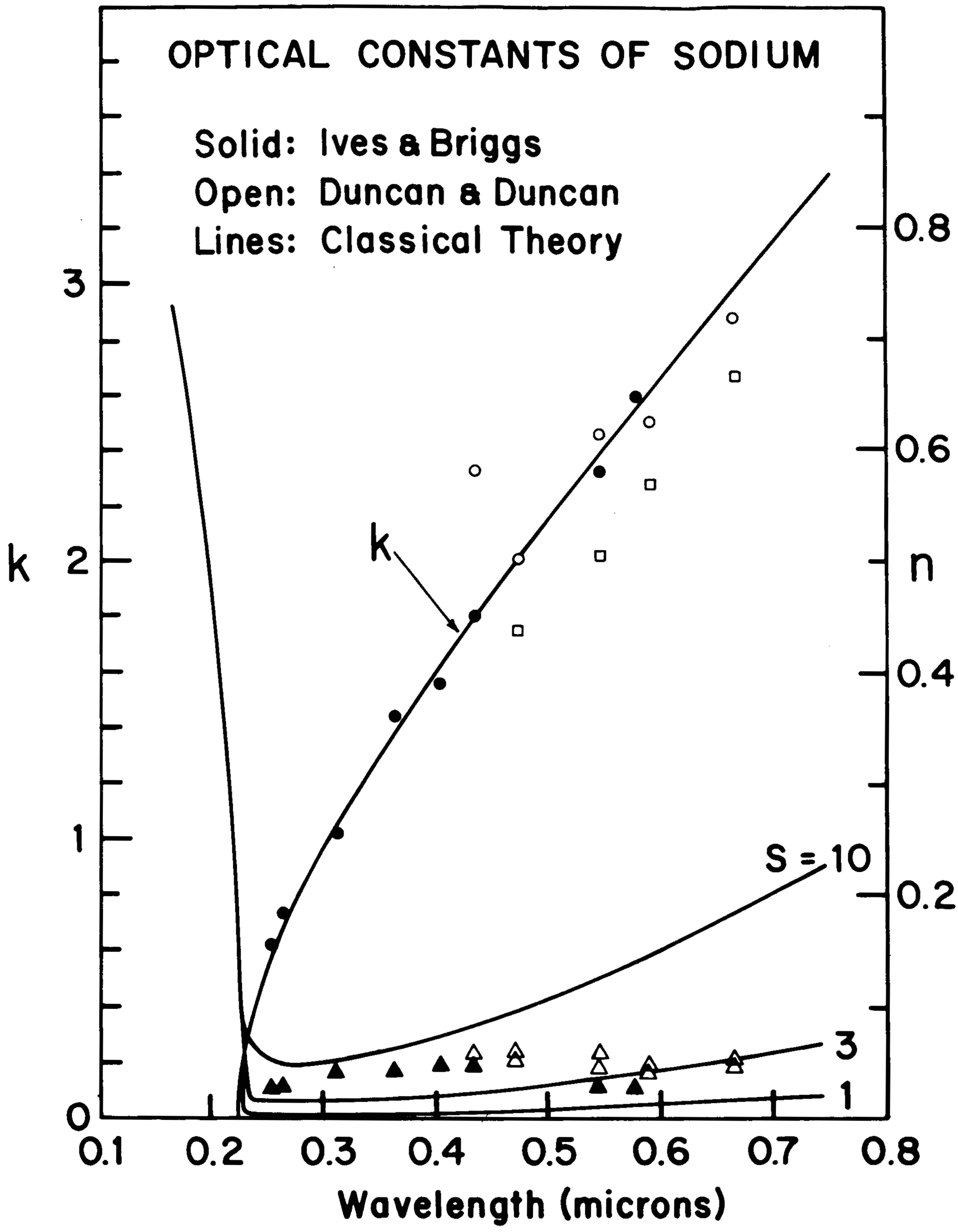

Figure 6.--Optical properties of metallic sodium. The lines are computed from the classical theory with the collision time divided by a factor S. The plotted points were determined from measured reflectivities of thick sodium films. Solid symbols: Ives and Briggs (1937). Open symbols: Duncan and Duncan (1913).

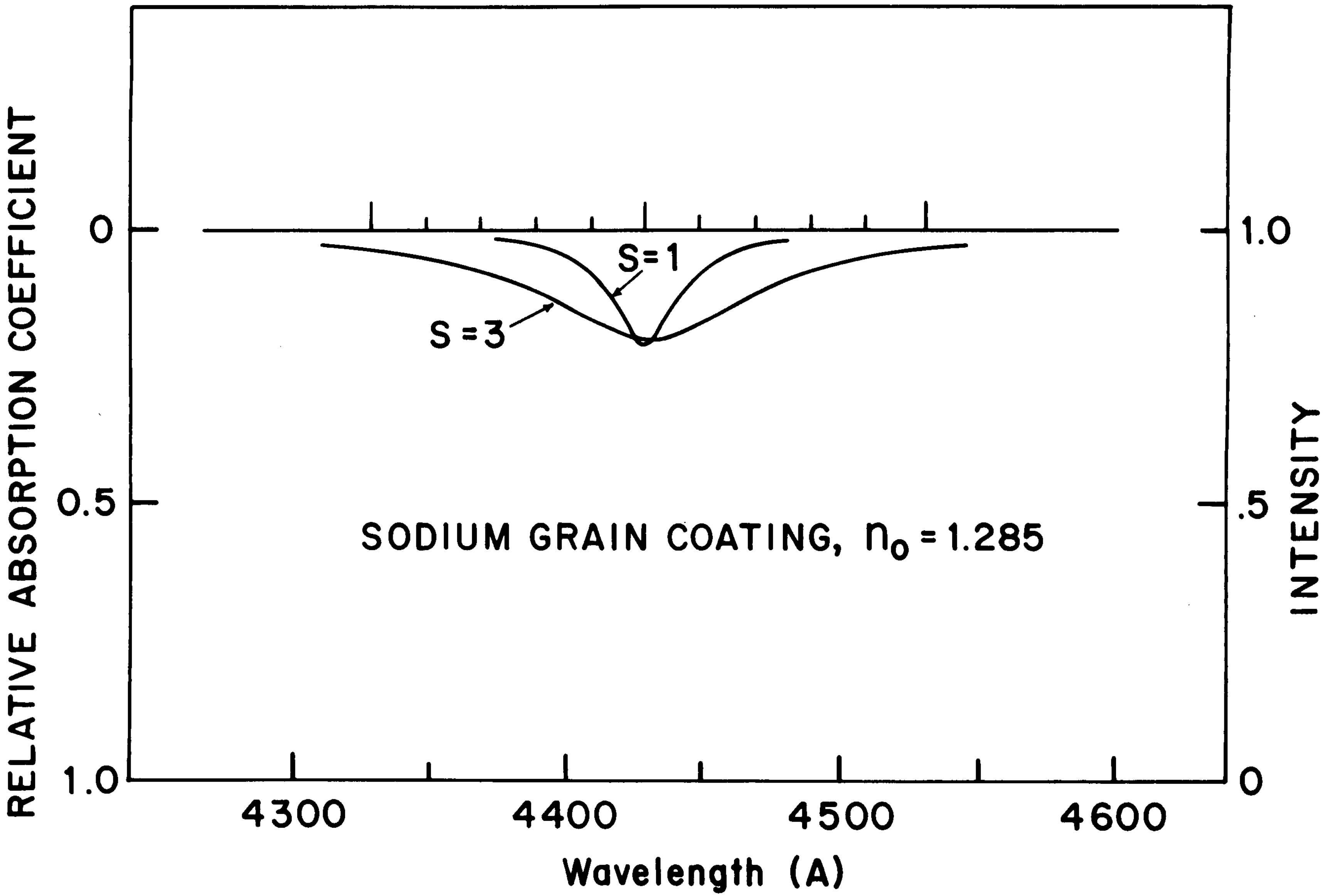

Figure 7.--Theoretical profile of Na colloid band computed with classical theory and an assumed index $n_0 = 1.285$ for the coating. The calculation assumes that the intensity dip is proportional to the absorption coefficient. The central dip is arbitrarily set at 0.20 to facilitate comparison with the observed profile shown in figure 1.

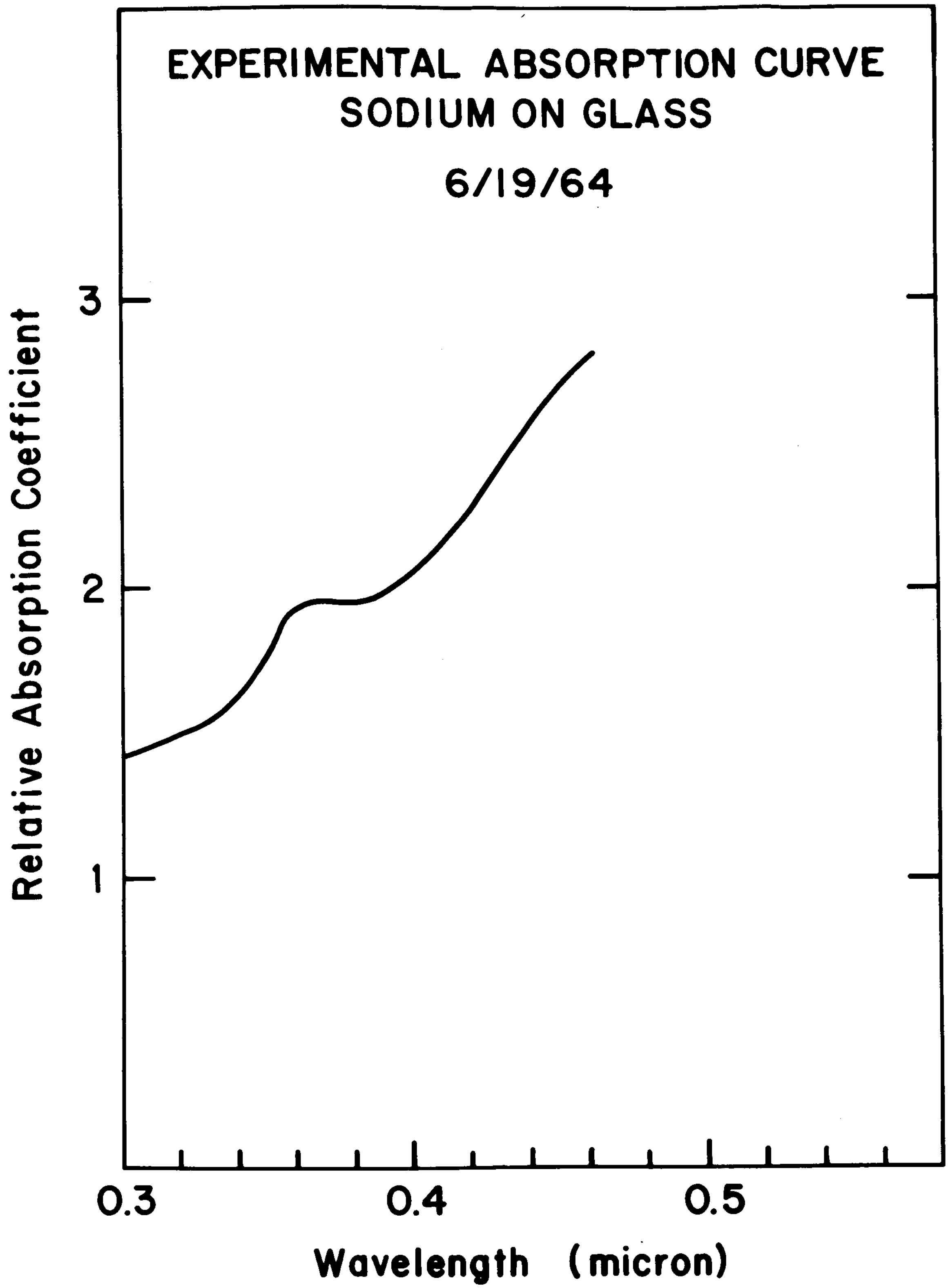

Figure 8.--Absorption curve for metallic Na deposited from vapor. The sample was prepared at the Smithsonian Astrophysical Observatory and measured at the AFCRL. The band at λ3600 agrees well in position and shape with prediction of theory.

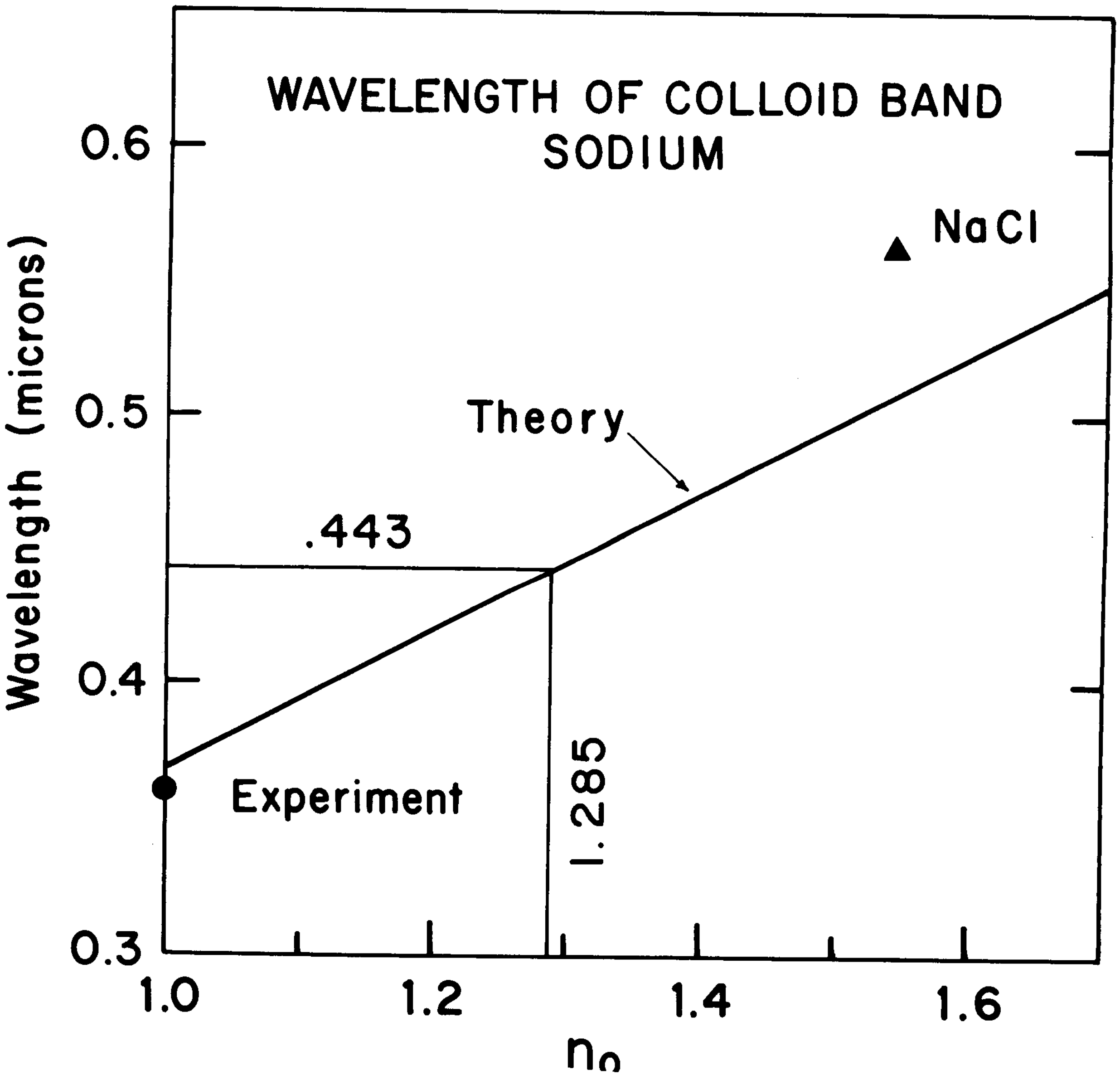

Figure 9.--Comparison between theoretical and experimental wavelengths of Na colloid band. Solid line computed from detailed theory. Triangle from solid NaCl and dot from present experiments (see figure 8).

References

DOREMUS, R. H.
1964. Optical properties of small gold particles. Journ. Chem. Phys., vol. 40, pp. 2389-2396.

DOYLE, W. T.
1958. Absorption of light by colloids in alkali halide crystals. Phys. Rev., vol. 111, pp. 1067-1072.

DUKE, D.
1951. Intensities of the interstellar band at λ4430. Astrophys. Journ., vol. 113, pp. 100-119.

DUNCAN, R. W., and DUNCAN, R. C.
1913. Optical constants of sodium and potassium. Phys. Rev., vol. 1, ser. 2, pp. 294-308.

GREENSTEIN, J. L., and ALLER, L. H.
1950. The interstellar λ4430 band. Astrophys. Journ., vol. 111, pp. 328-332.

IVES, H. E., and BRIGGS, H. B.
1937. Optical constants of sodium. Journ. Opt. Soc. Amer., vol. 27, pp. 181-185.

KITTEL, C.
1956. Introduction to Solid State Physics. John Wiley & Sons, New York.

MAXWELL GARNETT, J. C.
1904. Colors in metal glasses and in metallic films. Roy. Soc. Phil. Trans. (London), vol. 203A, pp. 385-420.

MIE, G.
1908. Beitrage zur Optik trüber Medien, Speziell Kolloidaler Metallösungen. Ann. d. Phys., Folge IV, Band 25, pp. 377-445.

RATCLIFFE, J. A.
1959. The Magneto-Ionic Theory and Its Applications to the Ionosphere. Cambridge University Press, Cambridge, England.

STOECKLY, R., and DRESSLER, K.
1964. On the interstellar λ4430 line. Astrophys. Journ., vol. 139, pp. 240-247.

UNSÖLD, A.
1962. On the interpretation of interstellar absorption bands. Z. für Astrophys., vol. 56, pp. 221-238.

WAMPLER, E. J.
1963. Systematic variations in the slope of the correlation between the intensity of λ4430 and color excess. Astrophys. Journ., vol. 137, pp. 1071-1079.

WILSON, R.
1960. The relation between interstellar extinction and polarization. Mon. Not. Roy. Astron. Soc., 120, pp. 51-63.

Appendix[7]

Bibliography on λ4430 Band

MERRILL, P. W. 1936, "Stationary Lines in the Spectrum of the Binary Star Boss 6142, "Ap.J., 83, 126.

Four interstellar lines have been known for years, viz., H and K of ionized calcium, D_1 and D_2 of neutral sodium. Recent observations at Mount Wilson have disclosed four additional detached lines whose approximate wavelengths are 5780.4, 5796.9, 6283.9, and 6613.9A; and another one, a vague feature near λ4427, is suspected....

BEALS, C. S., and BLANCHET, G. H. 1938, "An Absorption Line at λ4430.6 of Possibly Interstellar Origin," M. N., 98, 398.

A broad, ill-defined line about 40A in width and of approximate wavelength λ4430.5 has been observed in the spectra of a number of early type stars. The equivalent width of the line is shown to exhibit a marked correlation with that of interstellar K, suggesting that λ4430 may also be of interstellar origin. The diffuse character of the line has so far rendered unsuccessful any attempts to establish its stationary or non-stationary character in spectroscopic binaries. Possibilities for the origin of the line would appear to be limited to absorption by gaseous molecules or by particles of solid material in interstellar space.

MERRILL, P. W., and HUMASON, M. L. 1938, "The Diffuse Stationary Line λ4430 in the Spectrum of a Binary Star," P.A.S.P., 50, 212.

[The diffuse band λ4430 appears stationary in the spectrum of the binary star HD163181.]

SWINGS, P., and DESIRANT, M. 1939, "Les Raies ou Bandes d'Absorption Interstellaire non Encore Identifiees et leur Rapports avec l'Optique des Corps Solides aux Tres Basses Temperatures," Ciel et Terre, 55, 161.

[Experiments indicate that solids absorb light in fairly wide bands, so that it is possible that the unidentified interstellar bands may be due to solids at low temperatues. However, it is still not possible to know which solid is producing the bands.]

SHERMAN, F. 1939, "Note on the Interstellar Band at λ4430," Ap.J., 90, 630.

[The intensities of λ4430 were estimated visually in stars having various amounts of reddening. The increase in intensity of λ4430 was found to be closely correlated with that in reddening. A microphotometric tracing of a spectrum, at a dispersion of 60Å/mm of a B9 supergiant shows the band to be symmetric about 4428.6Å with a width of about 66Å.]

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[7] Abstracts enclosed in square brackets were provided by Miss Mary L. Drugan of the Smithsonian Astrophysical Observatory.

MORGAN, W. W. 1944, "Note on Interstellar Reddening in the Region of the Orion Nebula," Abstract, A.J., 51, 21.

[An examination of the spectra of several heavily reddened O stars indicates that the interstellar band at λ4430 is systematically weakened in regions around very hot stars.]

VAN DE HULST, H. C. 1949, "The Solid Particles in Interstellar Space," Recherches Astr. Obs. Utrecht, 11, Part 2, 47.

[Because of the impossibility of reconciling observations with the present theory of solid particles, the λ4430 band must arise from either free molecules or molecules on the surface of solid particles.]

BAKER, E. A. 1949, "Spectrophotometric Measurements on Early Type Stars. I," Pub. Roy. Obs. Edinburgh, 1, 15, pp. 31, 39.

[There is a strong correlation between color excess and λ4430 absorption, but none between D line intensities and λ4430 absorption.]

DUKE, D. 1951, "Intensities of the Interstellar Band at λ4430," Ap.J., 113, 100.

The central absorption of the broad interstellar band centered near λ4430 has been measured in some four hundred stars. When combined with spectroscopic parallaxes for the same stars, this material has made possible an investigation of the relationship between band intensity, on the one hand, and color excess and interstellar line intensity, on the other. A good correlation with color excess is found, and a much weaker one with distance; the correlation with the intensity of the interstellar D lines is intermediate between the other two. The band absorption appears to occur, in general, in regions where interstellar reddening is found; there are, however, some exceptions to the very close relationship between band absorption and reddening which seems to exist for the majority of the stars observed.

HERZBERG, G. 1955, Les Particules Solides dans les Astres, p. 326.

[Several objections are presented to the suggestion that diffuse interstellar lines arise in metal atoms or ions embedded in interstellar grains. 1) Even at low temperatures, groups of several lines should appear, rather than the individual lines observed. 2) Fe, Ti^{+}, and the rare earth elements are not sufficiently abundant to cause the observed lines. 3) It is necessary to postulate the existence of a very large amount of nonreddening interstellar dust.]

UNDERHILL, A. B. 1956, "An Investigation of the Strength of the Interstellar Absorption Feature at $\lambda 4430$ in the Spectra of O Stars," P.D.A.O. Victoria 10, 201.

Measurements of the equivalent width and central absorption of interstellar $\lambda 4430$ in the spectra of 60 O- and early B-type stars are presented. It is shown that a linear correlation exists between $W(\lambda 4430)$ and E_1, and that

$$E_1 = (0.15 \pm 0.01)W + (0.01 \pm 0.02) .$$

The following linear relations are found between distance and E_1 and between distance and $W(\lambda 4430)$:

$$r = (2.77 \pm 0.32)\, E_1 + (0.37 \pm 0.09)$$

and

$$r = (0.56 \pm 0.06)\, W + (0.37 \pm 0.10) .$$

Here r is in kiloparsecs, E_1 in magnitudes, and W in angstroms. Evidence is presented that the distribution in the plane of the galaxy of the interstellar material giving rise to the $\lambda 4430$ absorption and to the reddening is not completely uniform, although the assumption of uniformity is a good first approximation. A result of the linear relations between r and E_1 and between r and $W(\lambda 4430)$ is that logarithmic relations, which are demonstrated, exist between true distance modulus, $m_0 - M_v$, and E_1 and $W(\lambda 4430)$.

The connection between polarization and $W(\lambda 4430)$ and E_1 is investigated. It is found that single-valued relations, valid over the whole sky, between polarization and E_1 and $W(\lambda 4430)$ do not exist, although there is a weak linear correlation with $W(\lambda 4430)$. There is no linear correlation between polarization and E_1 .

WILSON, R. 1958, "Observations of Broad Interstellar Features at $\lambda\lambda 4430$, 4760, 4890, 6180," Ap.J., 128, 57.

The spectra of reddened and blue stars are obtained on the same plate. With the blue star as a standard, a method of reduction is used which allows a precise determination of the continuum in the spectrum of the reddened star. The broad interstellar feature at $\lambda 4430$ is shown to extend over some 150A, and its profile is determined. The reality of a broad feature at $\lambda 4760$, suspected by Merrill, is confirmed, and two similar features are found at $\lambda 4890$ and $\lambda 6180$.

BUTLER, H. E., and SEDDON, H. 1958, "Spectrophotometric Measurements of Early Type Stars. V.," Pub. Roy. Obs. Edinburgh, 2, 113.

Measures are given of numerous interstellar lines and bands, together with a profile of the band at 4430A. The relationship between interstellar line absorption and distance modulus is given. An absorption band centered at 4890A, similar in shape to that at 6180A and to that at 4430A, has been detected.

WILSON, R. 1960, "The Relation between Interstellar Extinction and Polarization," M.N., 120, 51.

[The equivalent width W of a diffuse interstellar line is predicted to be related to the grain polarizability by the following formula:

$$\frac{W}{E_{(B-V)}} = C \left(1 + \frac{0.7}{0.18} \frac{p}{E_{(B-V)}}\right) .$$

In the case of $\lambda4430$, however, the very high inaccuracy of the observational data masks the predicted correlation, if it does exist.]

HERBIG, G. H. 1963, "The Diffuse Interstellar Bands. I. A Possible Identification of $\lambda4430$," Ap.J., 137, 200.

Three strong band systems of H_2 having the metastable $C^3\,\pi_u$ state as their lower level are stongly concentrated in the region 4370-4500A, with center of gravity near 4430A. This complex structure contracts to essentially three lines centered near 4412A when the laboratory data are corrected to absorption at 60° K. It is pointed out that this H_2 feature, either at 60° K or under other conditions, if the individual lines were broadened by interatomic fields in the solid in which H_2 must be produced in space and if subjected to a matrix shift of reasonable amount, would constitute a good identification of the diffuse interstellar band at 4430A. Identification of the interstellar feature with H_2 would be particularly appropriate because of the strong correlation that is observed between the strength of $\lambda4430$ and the reddening by interstellar dust and because of requirements on the interstellar abundance of the absorber. It is probable that a higher rotational temperature would be simulated by the process that produces the H_2 metastables in space, in which case a smaller line broadening and matrix shift would be required. However, since the structure of the H_2 absorption band under interstellar conditions cannot now be predicted in detail, the identification discussed here should be regarded for the present only as a promising and rather reasonable possibility. If the identification is correct, then the production of sufficient metastable H_2 appears to be a serious problem under standard conditions; it may be that the only way is to postulate that $\lambda4430$ is produced in dust clouds lying near a hot star, under conditions of high radiation density or particle flux.

UNSÖLD, A. 1962, "On the Interpretation of Interstellar Absorption Bands," Zs. f. Ap., 56, 221.

The interstellar absorption bands ($\lambda 4430$, etc.) can be attributed to absorption by metallic particles with diameters $< \lambda$. Maxwell's theory requires that in the complex refractive index ($n = n - ik$), $k \approx \sqrt{2}$ and $n \ll 1$ in an absorption band. If a metal core is surrounded by a dielectric shell of refractive index n_0 , then in place of the vacuum-constants one should use the relative value λ/n_0 , as well as k/n_0 and n/n_0 . The Drude-Lorentz theory of metallic electrons shows that the frequency of the absorption bands is identical to the eigen-frequency of transverse plasma oscillations, $w_0 = w_c/\sqrt{3}$, where w_c is the critical frequency of the metal -- or, in other words, the frequency of the Langmuir longitudinal plasma oscillations. The width of the line depends in a simple manner on the direct current conductivity, σ_0 . The temperature dependence of the optical constants k and n can be discussed, and is found to be important in the case of the interstellar medium. The principal contribution to the interstellar bands is made by particles whose diameters range from 30A to 200A.

The comparison of theory with observation of the $\lambda 4430$ band for example, leads to plausible numerical values for the electron density, N_e, and the conductivity σ_0 of the enclosed metal core. The profile of the $\lambda 4430$ band is accurately reproduced. To explain the equivalent width of $\lambda 4430$, one must assume an average density of about 4.5×10^{-9} metal atoms/cc in the form of grains whose diameters are in the proper range (i.e., 30-200A). This density is compatible with the total density of interstellar matter. The order of magnitude of the density can be determined more exactly with the assumption that the interstellar dust ($\sim$ 1 percent of the mass) has, on the average, the same chemical composition as all the rest of the interstellar (population I) matter and that in the non-gaseous part of the matter a significant part of the metal has condensed in the form of conducting grains ($< \lambda$).

Because of the very strong dependence of the optical properties on the structure of the matter, as well as other difficulties, it is not yet possible to specify the precise origins of the different bands.

WAMPLER, E. J. 1963, "Systematic Variations in the Slope of the Correlation between the Intensity of $\lambda 4430$ and Color Excess," Ap.J., 137, 1071

Evidence is presented indicating that for a given color excess the strength of the interstellar feature at $\lambda 4430$ varies with galactic longitude. It also appears probable that this variation is strongly correlated with the slope of the reddening line.

GREENBERG, J. M., and LICHTENSTEIN, P. R. 1963, "The λ4430 Band and Interstellar Grain Temperatures," Abstract, A.J., 68, 74.

[A correlation or lack of correlation between the intensity of λ4430 and the value of A/E may suggest whether λ4430 is produced within interstellar grains or in molecules on their surfaces.]

STOECKLY, R., and DRESSLER, K. 1964, "On the Interstellar λ4430 Line," Ap.J., 139, 240.

Photoelectric intensity measurements of this line are presented for fifty-nine stars. These combined with the data of Duke (1951) provide evidence for a weakening of λ4430 absorption relative to color excess in stars showing high negative interstellar Ca II velocities. It is suggested that λ4430 extinction originates primarily in very small grains which may be selectively evaporated in regions near hot stars. The line may therefore be a valuable tool for studying the size distribution of interstellar grains.

NOTICE

This series of Special Reports was instituted under the supervision of Dr. F. L. Whipple, Director of the Astrophysical Observatory of the Smithsonian Institution, shortly after the launching of the first artificial earth satellite on October 4, 1957. Contributions come from the Staff of the Observatory. First issued to ensure the immediate dissemination of data for satellite tracking, the Reports have continued to provide a rapid distribution of catalogs of satellite observations, orbital information, and preliminary results of data analyses prior to formal publication in the appropriate journals.

Edited and produced under the supervision of Mr. E. N. Hayes and Mrs. Barbara J. Mello, the reports are indexed by the Science and Technology Division of the Library of Congress, and are regularly distributed to all institutions participating in the U. S. space research program and to individual scientists who request them from the Administrative Officer, Technical Information, Smithsonian Astrophysical Observatory, Cambridge, Massachusetts 02138.